3.2 GEOLOGY, SOILS, AND SEISMICITY

3.2.1 Affected Environment

3.2.1.1 Geology and Geomorphology

Table 3.2-1 describes the geology of the pipeline corridor. Information in the table is primarily based on a compilation of published geologic maps, supplemented with local aerial photo analysis and ground reconnaissance. The map atlas in Appendix A of the ASC shows the distribution of soil and rock units along the corridor (OPL 1998).

3.2.1.2 Soils and Erosion, Mass Wasting, and Landslides

Soils and Erosion. The physical characteristics of a soil (e.g., grain size, sorting, density or degree of compaction, and composition) dramatically impact its mechanical behavior with respect to erosion, mass wasting, and liquefaction potential. The type of soil that has formed or been deposited in an area is also an indicator of the surface processes that have affected (and may continue to affect) the area. This subsection addresses soil type with respect to erosion potential; mass wasting and liquefaction are discussed in later subsections.

The soil types along the pipeline corridor are shown on the soil types and erosion hazard maps in Appendix B of the ASC. These maps also indicate the relative susceptibility of the various soil units along the pipeline corridor to erosion. Soil units that have moderate or high potential for soil erosion are delineated based on soil type, physiographic setting, and drainage conditions. The soil units and erosion designations shown on these maps are from soil surveys of the Natural Resources Conservation Service (NRCS).

Soils along the pipeline corridor can be divided into two general types based on their geographic position and genesis:

- Soils west of Ellensburg are generally associated with glacially deposited materials, materials weathered from bedrock, and sediments deposited in alluvial valleys. These soils, because of their physical properties and the climatic environment in which they are situated, are impacted primarily by water-related erosion.

- East of Ellensburg, the soils consist of wind-blown silt and sand, materials weathered from bedrock, alluvium, and Pleistocene flood deposits. These soils are subject to both water- and wind-related erosion because, in general, they are finer grained than the soils to the west, often are not as well consolidated, and occupy a drier environment.

Areas of identified high erosion potential along the pipeline corridor include steep sidewalls of creeks and river drainages, alluvial soils in the larger stream valleys, and windblown silt (loess soil) in eastern Washington. Between the proposed Thrasher Pump Station and North Bend, areas of high

Table 3.2-1. Geology and Geomorphology along Pipeline Corridor

Pipeline Segment and Mileposts*	Description
Thrasher Pump Station to Snoqualmie MP 0 to MP 33	This segment would traverse the Puget Lowland, a structural basin filled with a thick sequence of unconsolidated sediments. The relatively level basin fill was subsequently dissected resulting in a network of creeks and rivers with steep side slopes. Geology along this segment (Map Atlas pages 1 through 14) consists predominantly of unconsolidated deposits laid down during most recent glaciation (Vashon Stade of the Fraser glaciation). This glacier originated in the area that is now British Columbia and covered the central Puget Lowland between about 15,000 and 13,500 years ago (Easterbrook 1986; Booth 1987). Vashon ice sheet eroded topography and deposited sediment transported by the advancing ice mass and meltwater streams. Layered strata of clay, clayey silt, silt, sand, gravel, and boulders were deposited. Deposits are very dense or hard where they were overridden by glacial ice, and loose to medium dense or soft to very stiff where they were not overridden. As few as three and perhaps as many as five glaciers deposited sediment (Qpf) prior to the most recent Vashon Stade glaciation. Glacial outwash (Qgo), consisting of granular soil deposited by streams and rivers flowing from the glaciers, was deposited both during advance and recession of glacial events. Glacial outwash is exposed throughout this area, most commonly within present-day stream valleys. Glacial outwash typically is moderately dense where it overlies the most recent glacial till and very dense where it underlies this till. Sediments deposited at the base of glacial ice mass were overridden and consolidated to form a very compact deposit known as glacial till (Qgt). Till is generally present near ground surface along much of this segment and at Thrasher Pump Station. Post-glacial alluvial deposits (Qa) along this segment occur in stream and river valleys, most notably in Snohomish River, Cherry Creek, Tolt River, and Snoqualmie River Valleys. They typically consist of sand, gravel, silt, and clay deposits having low to moderate densities. Deposits can range in thickness from a less than a meter in small stream valleys to several tens of meters thick in larger river valleys. Mass wasting deposits (Qls) have been mapped on steep slopes on south sides of Cherry Creek (atlas page 8) and Tolt River (atlas page 11). They are discussed in text with respect to potential impacts on the project. Isolated exposures of sedimentary bedrock (Ts) occur throughout this segment. The longest segment that would pass through exposed bedrock extends 7.2 km (4.5 miles) from Peoples Creek (stream crossing 15 on atlas page 6) to North Fork Cherry Creek Tributary (stream crossing 18 on atlas page 7). Bedrock consists of Tertiary-aged andesite (Tan), a relatively massive volcanic rock that is typically hard in fresh exposures.
Snoqualmie to I-90 East of North Bend MP 33 to MP 38	Snoqualmie River Valley, from approximately stream crossing 37 (atlas page 14) to South Fork Snoqualmie River at stream crossing 43 (atlas page 17), is underlain by relatively loose alluvial silt, sand, and gravel (Qa) (Frizzell et al. 1984). The Snoqualmie River is one of the principal east-west rivers draining central portion of Cascade Range. In the vicinity of Snoqualmie, it is a broad floodplain with an underfit active stream channel. Bedrock underlies alluvium at depth, but is expected to occur below anticipated depth of installation for pipeline. Thickness of alluvium is

Pipeline Segment and Mileposts*	Description
	reported to be greater than 15 m (50 feet) in the area of crossing 38 of the Snoqualmie River (atlas page 14) (Dames & Moore, 1977a and 1977b). Groundwater in deposits is relatively shallow and generally coincident with water level in Snoqualmie River.
I-90 East of North Bend to the Western Tunnel Portal MP 38 to MP 55 National Forest Service Lands (MP 45 to MP 55)	This portion of Snoqualmie River Valley is U-shaped, formed by scouring of last continental and alpine glacial ice. Valley sides are mantled with glacial deposits that have been incised or overridden by subsequent alluvial fans or landslides that emanate from side channels to main valley. Pipeline corridor between crossing of stream 43 east of I-90 (atlas page 17) and western portal of the railroad tunnel immediately east of Rockdale Creek (stream crossing 84 on atlas page 24) is underlain by the following deposits: (1) relatively loose alluvium (Qa) and moderately dense glacial outwash (Qgo) (both consisting of mixtures of silt, sand and gravel) within valley floors; (2) glacial ice contact deposits (Qgi) consisting of relatively compact mixtures of clay, silt, sand, gravel, and minor fill in isolated pockets along the valley flanks; (3) local landslide deposits (Qls) and avalanche deposits (Avl), and (4) bedrock at relatively shallow depths along steeper valley sidewalls. Tertiary-age bedrock has been mapped as marine sandstone and argillite (Tar); volcanics (Tv); granite (Tg); metagabbro (Tmg); rhyolite (Trh); and sandstone, siltstone, shale, and conglomerate (Ts) (Frizzell et al. 1984).
Western Tunnel Portal to the Crossing of the Yakima River MP 55 to MP 102 National Forest Service Lands (MP 55 to MP 75)	This segment (atlas pages 24 to 41) extends from steep slopes and rugged terrain at crest of Cascade Mountains to wide-open topography along western edge of Columbia Plateau. In the vicinity of the former railroad tunnel at Snoqualmie Pass, surface geology has been mapped primarily as Tertiary-age rhyolite (Trh) and sedimentary bedrock (Ts) consisting primarily of shale, siltstone, sandstone, and conglomerate (atlas pages 24 and 25). Rocks have been folded at right angles to pipeline corridor, with the crest of a broad anticline between Surveyors Lake and Hyak Lake. Between eastern tunnel portal (atlas page 25) and Stampede Pump Station (atlas page 28), pipeline corridor is underlain primarily by alpine glacial deposits (Qag) and Tertiary bedrock units including rhyolite (Trh), sedimentary rock (Ts), volcanics (Tv), and tuff and breccia (Ttu).
	The segment between Stampede Pump Station and Lake Easton (atlas page 32) is underlain by Quaternary alluvium (Qa), glacial till (Qgt), and alpine glacial deposits (Qag) within Yakima Valley bottom, and Tertiary bedrock along valley walls consisting of rhyolite (Trh), volcanics (Tv), and Naches Formation volcanic and sedimentary strata (Tn). This section would also cross the toe of an avalanche runout zone (Avl) and through the toe of a dormant landslide (Qls).
Yakima River to Kittitas Terminal MP 102 to MP 119	Topography and geology between Yakima River crossing (atlas page 41) and Kittitas Terminal (atlas page 52) vary widely. At proposed Yakima River crossing, valley bottom is underlain by loose to medium dense alluvium (Qa) (USGS 1983); eastern slope of valley is dominated by a large landslide deposit (Qls). OPL investigated geotechnical conditions at this proposed crossing with three borings and a bathymetric survey of the river. Two borings on the west side of the Yakima River encountered low to moderate density sand and moderately dense silt with low plasticity.

Pipeline Segment and Mileposts*	Description
	Borings closest to river encountered an underlying layer of medium dense to dense, poorly graded gravel. Landslide materials were not identified in samples taken from these borings. Water depth at the crossing was less than 2 m (6.6 feet) (Dames & Moore 1996). East of Yakima River crossing, pipeline corridor would cross moderate slopes underlain by glacial till (Qgt) and shallow Tertiary basalt (Tb). Remainder of this segment to Kittitas Terminal would cross gentle to moderate slopes generally underlain by Quaternary alluvial deposits (Qa and Qoa) and isolated Tertiary basalt exposures (atlas page 47). Alluvial sediments are clay-rich sands and gravels that were deposited in a series of coalesced alluvial fans. In many places, streams that cross this section of pipeline corridor eroded into older alluvial gravels (Tal) of similar depositional style, but which now form higher terraces.
Kittitas Terminal to the Columbia River MP 119 to MP 149	East of Kittitas Terminal, corridor continues across level alluvial fill in the Ellensburg basin, then climbs through dissected basalt flows. This section of pipeline corridor includes a series of alternate routes primarily underlain by Tertiary basalt (Tb) bedrock. Relatively narrow deposits of Quaternary alluvium (Qa) underlie Johnson Canyon and Canyon Creek, and Quaternary fluvial gravel (Qfg) underlies terraces west of Columbia River. Several landslides (Qls) are located in hills just west of Columbia River (atlas pages 61, 62, and 62a). Fill (f) is also present along portions of I-90 and across the mouth of Getty's Cove.
Columbia River Crossing MP 149 to 150	On west side of Columbia River, surficial deposits consist of either fill (f), alluvium (Qa), fluvial gravel (Qfg) or basalt (Tb). All four alternatives for crossing Columbia River have generally the same geologic features in upland areas adjoining the river. Basalt (Tb) or fluvial gravel (Qfg) underlies the alternate approaches on either side of the river. The proposed pipeline corridor passes through a massive landslide deposit (Qls) at MP 145 (atlas page 62a). Within the river channel, alluvial deposits underlying the river channel behind the dam likely include considerably more silt, sand, and clay than those downstream from the dam. Because of ponding effect of the dam, finer grained sediments have accumulated on the streambed behind the dam; scouring and lack of sediment influx have removed finer sediments from streambed below dam.
	The Quaternary fluvial gravel, also known as flood gravel (Qfg), consists of Pleistocene deposits (approximately 15,000 to 12,000 years before present) associated with Lake Missoula floods -- catastrophic events that passed through eastern Washington to Columbia River Gorge following episodic breaks of a glacial dam on Clark Fork River in Montana. Remainder of pipeline corridor, from Columbia River to pipeline terminus at Pasco, crosses landforms shaped by these ancient floods.
Columbia River Crossing to Corfu Alternate Route MP 150	Each of the proposed alternate routes would cross Quaternary fluvial gravel (Qfg), Quaternary sand and silt deposits (Qs), and Tertiary basalt (Tb) between Columbia River and Beverly-Burke Pump Station (atlas page 66). East of Beverly-Burke Station, ground surface is a relatively level plane cut by dry washes eroded during Lake Missoula floods. This section of corridor is underlain primarily by bedrock of Tertiary Ringold Formation (Grolier and Bingham 1971) with scattered exposures of Columbia River Basalt (Tb). Ringold Formation (Tre and Trl) in this area is weakly indurated fine, silty sand. Pipeline would parallel State Route 26, crossing primarily basalt (Tb) with only minor occurrences of Ringold Formation and fluvial gravel (Qfg). Immediately east of stream crossing 240 (atlas page 75), basalt is overlain by thick fluvial gravel to end of segment.

Pipeline Segment and Mileposts*	Description
Corfu Landslide and Reroute Around Corfu Landslide MP 173 to MP 178	This segment from beginning to end of Corfu alternate route (atlas pages 77 through 80) would bypass Corfu Landslide by following an alignment along State Highway 26 and crossing Lower Crab Creek and several tributaries. Fluvial gravel (Qfg), alluvium (Qa), and basalt (Tb) underlie first 8 km (5 miles) of this alternate route. It would then turn south (atlas page 80) and cross an area underlain by Ringold Formation lacustrine deposits (Trl) before intersecting original pipeline corridor.
Corfu to Wahluke Slope MP 178 to MP 189	East of Corfu Landslide to Wahluke Slope (atlas pages 80 through 82), pipeline corridor would cross through approximately 5.8 km (3.7 miles) of Ringold Formation lacustrine deposits (Trl) along northern flank of Saddle Mountains. Pipeline would then cross deformed basalt (Tb) and Quaternary loess (Ql) deposits at Wahluke Slope (Grolier and Bingham 1971).
Wahluke Slope to the Othello Channel MP 189 to MP 194	From Wahluke Slope to Othello Channel (atlas pages 82 through 86), pipeline corridor would cross relatively level terrace underlain by loess (Ql), fluvial gravel (Qfg), and Quaternary fluvial/lacustrine sand (Qs). At Wahluke Slope, pipeline corridor turns south across plains underlain by loess (Ql) to beyond Othello Pump Station (atlas page 83). Farther south and southeast, pipeline corridor crosses fluvial/ lacustrine sand (Qs), Ringold Formation (Tru), and sand and gravel flood deposits derived from Lake Missoula floods (Qfg) (Grolier and Bingham 1971).
Othello Channel MP 194 to MP 203	Pipeline corridor would cross Othello Channel (atlas pages 86 and 90). Channel has a present-day relief of approximately 60 m (197 feet), was eroded during Lake Missoula floods, is reportedly eroded approximately 100 m (328 feet) into underlying basalt bedrock, and extends from north of Othello to Columbia River. Channel is underlain by flood gravels and lacustrine deposits above bedrock surface (Grolier and Bingham 1971).
	South of stream crossing 261, pipeline corridor would parallel upper edge of a landslide complex that has developed in Ringold lacustrine deposits (Trl) on steep slope along edge of Othello Channel. After crossing this area, pipeline would drop approximately 60 m (197 feet) in elevation into the channel down a slope underlain by Ringold Formation deposits. At floor of channel (atlas page 87), pipeline would cross relatively level ground underlain by Tertiary basalt (Tb) for approximately the first 5 km (3 miles), followed by alternating deposits of fluvial gravel (Qfg) and fluvial/lacustrine sand (Qs). At eastern wall of channel, pipeline corridor rises back up through deposits of Ringold Formation (atlas page 90).
Othello Channel to Pasco MP 203 to MP 227	Pipeline corridor would continue south and southeast from Othello Channel to terminal at Pasco (atlas pages 90 through 100). Geology throughout this section is characterized primarily by fluvial and lacustrine sand (Qs) with minor deposits of fluvial gravel (Qfg); alluvium (Qa); and lacustrine clay, silt, and fine sand of Ringold Formation (Trl).

Note: See the appropriate maps and geologic units (shown in parentheses) within the map atlas for maps of the geology and topography along the pipeline corridor.

* Mileposts are approximate.

erosion potential include the valley walls adjoining Peoples Creek, Cherry Creek, and the Tolt River. Typically the soils that are most susceptible in these environments are glacial outwash sands. These deposits are susceptible to gullying, particularly where surrounding land use changes modify surface water pathways and volumes.

Along the South Fork Snoqualmie River Valley, the corridor crosses tracts of flat land on the valley floor that are characterized as having high erosion potential. These unconsolidated granular soils are subject to stream erosion during flood events. To the east, where the corridor passes through the Cascade Mountains, it typically either crosses along or borders on relatively steep sideslopes, and crosses many stream valleys. The soils on the sideslopes have either moderate or high erosion potential, and soils on the stream valley slopes and floors have high erosion potential.

East of Ellensburg, the pipeline corridor is underlain by soils that are generally finer grained and subject to both wind and water erosion, depending on their location. Much of the upland area along this section of the corridor is underlain by loess deposits that can be easily eroded by wind when the vegetation is removed or disrupted. These soils are also subject to severe gullying where surface water can be channeled over them. The Soil Survey of Grant County indicates that the loess soil mantling the east end of Saddle Mountain is susceptible to such erosion. The ASC map atlas also identifies coarser soils in this area that have high erosion potential, primarily where they mantle or comprise relatively steep slopes. For example, deep gullies were observed in the relatively weakly consolidated soils of the Ringold Formation on the east edge of the Othello Channel.

Mass Wasting. Mass wasting (slide movement) is an ongoing geologic process along portions of the pipeline corridor. Table 3.2-2 provides an inventory of 47 instances of mass wasting along the pipeline corridor -- 23 west of the crest of the Cascades and 24 east of the crest. The mass wasting features listed in this inventory include steep slope areas, areas identified on geologic maps as landslides, landslide features visible on aerial photographs, and areas of mass wasting that were identified during aerial or ground reconnaissance. These mass wasting features include slumps, debris avalanches, debris flows, and snow avalanches. Some are deep-seated and others are shallow; for this discussion, a shallow slide is defined as less than 3 m (10 feet) deep, and a deep-seated slide is one in which the slide plane is greater than 3 m (10 feet) below the ground surface.

OPL evaluated the mass wasting sites identified in the inventory to determine their orientations relative to the proposed pipeline, to assess their potential to incur deep or shallow movement, and to evaluate means of mitigating the landslide potential through avoidance, monitoring, and engineering remedial measures. Field evaluations included aerial and ground reconnaissance, hand auger borings at seven of the sites to evaluate the near-surface soils, and soil borings using a drill rig at nine other sites to evaluate deeper subsurface conditions. The results of these explorations are summarized in Table 3.2-2. Additional subsurface exploration deemed necessary for design and construction is discussed in the AAdditional Proposed Mitigation Measures@ at the end of this section.

Table 3.2-2. Mass Wasting Inventory

Atlas page	Stream crossing	Slope height (feet)	Slope angle	Pipeline orientation to slope			Geologic Unit[c]	Field visit	Field Investigation	Existing Landslides		
				Perpendicular	Parallel	Position on Slope				Dormant Deep	Active Shallow[a]	Active Deep[b]
4	E of 9	100	3H:1V	x			Qgt	yes	soil boring			
5	W of 11	200	5H:1V	x			Qgt/Qtb/ Qpg	yes	shovel & visual			
5	12&13	150	2.5H:1V	x			Qgo	yes	soil boring			
6	14&15	200	2.5H:1V	x			Qgt/Tan	yes	soil boring		x	
8	20	100	3.5H:1V	x			Qgt	yes	soil boring		x	x
8	21	100	3H:1V	x			Qgo	yes	area visual			
11	NW of 26	200	5H:1V	x			Qgo/Qpf	yes	shovel & visual			
11	SW of 27	300	3H:1V	x			Qls	yes	visual			x
12	N of 28	150	3H:1V	x			Qpf/Qgo	yes	soil boring			
12	S of 28	300	3H:1V	x			Qpf/Qgo	yes	soil boring			
14	37	100	8H:1V		x	near toe	Qpf	yes	soil boring			
17	N of 44	150	2.5H:1V		x	mid-height	Qgt	yes	soil boring			
17	S of 44	100	2H:1V	x			Qgi	yes				
18	46 to 49[d]	600	2H:1V		x	mid-height	Tv/Qgo	yes	visual			
18	45&46[d]	150	1.5H:1V		x	mid-height	Tg/Qgo	yes	visual			
19	50 to 56	<600	2H:1V		x	toe	Tg/Qgo	yes	shovel & visual			
20	59 to 61[e]	700	2H:1V		x	lower	Tg/Qls	yes	shovel & visual	x		
21	63[e]	>400	2.5H:1V		x	lower	Qa	yes	visual			
21	67[e]	>400	2.5H:1V		x	lower	Qa	yes	visual			
21	68[e]	<500	2H:1V		x	lower	Qgo	yes	visual			
23	W of 78[e]	>500	2.5H:1V		x	toe/lower	Tg/Qa	yes	hand auger			
23	E of 78[e]	>500	2H:1V		x	lower	Tg/Qa	yes	aerial			
24	E of 83	>500	2H:1V		x	lower	Ts	yes	aerial			
25	N of 85[e]	300	1.75H:1 V		x	toe	Ts/talus	yes	aerial			
26	92 to 93[e]	<600	3H:1V		x	toe	Ttu/Tv/Avl	yes	aerial			
26	N of 94[e]	<500	2H:1V		x	toe	Ttu	yes	aerial			
30	114	<300	3H:1V		x	toe	Tn/Trh/Qls	yes	aerial	x	x	
31	W of 115	200	3H:1V		x	toe	Qls	yes	aerial & visual	x		
37	E of 134	<200	6H:1V		x	lower	Qf/Qls	yes	hand auger	x		
38	W of 135	>200	5H:1V		x	lower	Qls	yes	hand auger	x		
41	W of 145	250	3H:1V		x	toe	Qls	yes	hand auger	x		
41	W of 147	200	3.5H:1V	x			Qls	yes	soil boring	x		
42	147&148	200	7H:1V	x			Qls	yes	hand auger	x		
42	E of 148	800	2H:1V	x			Tb	yes	aerial & visual		x	
43	W of 151	550	2.5H:1V	x			Tb/Qls	yes	aerial	x		
43	E of 152	650	3H:1V	x			Tb	yes	aerial			

Table 3.2-2. Mass Wasting Inventory

Atlas page	Stream crossing	Slope height (feet)	Slope angle	Pipeline orientation to slope			Geologic Unit[c]	Field visit	Field Investigation	Existing Landslides		
				Perpendicular	Parallel	Position on Slope				Dormant Deep	Active Shallow[a]	Active Deep[b]
43	152-153	200	3.5H:1V	x			Tb	yes	aerial			
44	E of 156	100	3H:1V	x			Tal	yes	hand auger			
45	157	100	3H:1V	x			Tal	yes	hand auger			
61a/ 62a	Alt 14	500	5.5H:1V		x	toe	Qls	yes	aerial	x		
82	255[f]	>100	5.5H:1V		x	lower	Tb	yes	aerial			
The following Mass Wasting locations were found on alternative pipeline routes and are not located within the proposed route.												
61	9a	100	10H:1V	x			Qls/Tb	yes	aerial	x		
61	Alt 3	300	7.5H:1V		x	head	Qls/Tb	yes	aerial	x		
61	Alt 13	350	4.5H:1V		x	head	Qls/Tb	yes	aerial	x		
62/62a	Alt 13	550	8H:1V	x			Qls	yes	aerial	x		
62a	16b-16g	300	7.5H:1V		x	mid-height	Qfg	yes	aerial			
62b	N of 16a	400	3H:1V		x	mid-height	Qfg	yes	aerial			
63a	SE of 24e	400	5H:1V	x			Qfg/Tb	yes	aerial			
78a/79	E of 246	>300	2.5H:1V		x	toe	Qls	yes	aerial	x		
80a	250-251	>300	6H:1V		x	mid-height	Ql/Tri	yes	aerial			
86 & 87	S of 261[f]	>100	3H:1V		x	upper	Qls/Qfg/Tb	yes	aerial		x	x

Source: Based on OPL 1998.

[a] less than 10 feet deep
[b] greater than 10 feet deep
[c] see geologic and hazard map legend for geologic unit definitions
[d] occurs on federal lands administered by the U.S. Bureau of Land Management
[e] occurs on federal lands administered by the U.S. Forest Service
[f] occurs on federal lands administered by the U.S. Bureau of Reclamation
aerial - visual aerial survey via helicopter

Five of the landslides identified in the inventory are specifically addressed here because they are considered to be more important than others with respect to the safety of the pipeline:

- Peoples Creek and Cherry Creek stream crossings,
- an active landslide on the southeast slope of the Tolt River Valley,
- the slopes on either side of the Yakima River Valley, and
- the slope west of the proposed Columbia River crossing.

These landslides are discussed in the following sections. The large Corfu Landslide was avoided by routing the centerline 1,200 to 2,800 m (3,937 to 9,186 feet) north of the toe of the landslide. BMPs and mitigation measures are included to address all other areas.

Peoples Creek Landslide. At Peoples Creek (stream crossing 15), the pipeline corridor would cross at right angles to the ground contours. The ravine is incised about 18 to 21 m (59 to 69 feet) into the surrounding plateau. The lower 10 m (30 feet) of the slope is underlain by weathered andesite, and the upper portion of the slope is glacial soil. Near-surface soil on the steeper, lower slope is raveling and slumping into the creek from both banks.

Cherry Creek Landslide. At Cherry Creek (stream crossing 20), the slopes on the north side of the creek are moderate and stable; however, the slopes on the south side are steep and unstable. There are multiple active slides along about 300 m (985 feet) of creek bank. The slope instability appears to be related to surface water and groundwater seepage, in combination with steep slopes and weak glacial soils. Some of the sliding is obviously shallow; however, one of the slides appears to be much deeper and related to groundwater pressure deeper within the slope. Much of the slide debris has landed in the creek or on the narrow terrace adjacent to the creek.

Tolt River Valley Landslide. A large, active, deep-seated landslide is located on the southeast slope of the Tolt River Valley where the pipeline would cross the river (stream crossings 26 and 27). This landslide is about 0.8 km (0.5 mile) wide and ranges in elevation from 46 m (151 feet) at the toe along the river to about 183 m (600 feet) at the top of the headscarp. This slide has probably been active for thousands of years. Although no fresh features were observed on the body of the slide mass, the scarps were not rounded and subtle, indicating probable periodic movement. Movement of the soil is likely to be coincident with high groundwater levels and seismic shaking. The body of the slide has not been explored with deep borings yet; however, based on the size, configuration, and large scale of the slide mass, the base of the sliding plane is most likely very deep.

Yakima River Valley Landslide. The east and west slopes of the Yakima River Valley at the pipeline crossing (stream crossing 147) are mapped as landslides; however, reconnaissance and drilling did not indicate that the slides are active. Nevertheless, these dormant slides could potentially be activated by seismic activity and/or high groundwater pressure. Based on the size of these features, it is apparent that they are deep-seated.

Columbia River Crossing Landslides. Just west of the proposed Columbia River crossings is a group of several landslides. The largest of these slides, which is located south of Vantage, is over 2 km (1.2 miles) wide. It has a high but rounded headscarp and rounded hummocky topography at the toe of the slope, both indicative of a dormant landslide. The proposed pipeline corridor traverses through the middle of this landslide mass, parallel to the topographic contours. Some of the land on the headscarp is bare, indicating active erosion. The second largest slide is north of I-90, on a slope that overlooks the freeway and is immediately south and downslope from the proposed pipeline. This feature also appears to be dormant, not having sharp or fresh scarps.

3.2.1.3 Topography

In the Puget Lowland at the west end of the pipeline corridor, the relatively low and level glacial fill has been dissected by post-glacial streams, which have steep side slopes. In general, the ground surface elevations range between 90 and 150 m (295 and 492 feet); however, east of the Snoqualmie River mainstem valley, the corridor reaches elevations of about 300 m (985 feet). The pipeline corridor then drops down and penetrates into the central Cascade Range along the south edge of the U-shaped valley of the Snoqualmie River, rising slowly, nearly to the crest of Snoqualmie Pass at about 760 m (2,493 feet) elevation. Along the valley, the corridor would traverse many creeks and rivers that flow into the valley from the south.

The corridor then continues eastward through the central Cascades, following the south side of the U-shaped Yakima River Valley. The topography along this part of the pipeline corridor is not particularly steep, but the mountain slopes to the south are somewhat precipitous. The pipeline corridor then emerges into the Ellensburg Basin, a combination of basalt-based level ridges with steep sidewalls and broad coalesced alluvial fans. The basin is a relatively flat featureless plain east of Ellensburg, until it rises through Johnson Canyon and into the dissected Ryegrass Mountains. Just west of the Columbia River the ground surface along the pipeline corridor drops about 120 m (394 feet) into the Columbia River Gorge. This wide gorge would be crossed at about elevation 150 m (492 feet).

East of the Columbia River Gorge, the corridor crosses level ground at an elevation of about 335 to 366 m (1,100 to 1,200 feet); this area is periodically cut by dry washes. Where the pipeline corridor bends to the southeast, it crosses lower Crab Creek, before rising again to pass over the east end of the Saddle Mountains. At the east end of this ridge, the corridor gains about 90 m (295 feet) in elevation above lower Crab Creek before dropping down again to the south to a broad terrace (Wahluke Slope). Descending the east slope of the terrace, the pipeline then crosses the Othello and Esquatzel Channels, which are remnants of erosion by the late-Pleistocene Lake Missoula floods. The elevation ranges from about 228 to 275 m (750 to 900 feet) across this scoured topography. The elevation of the ground surface at the south terminus of the pipeline corridor is approximately 122 m (400 feet).

3.2.1.4 Unique Physical Features

There are three unique physical features within or near the pipeline corridor: the Corfu Landslide, the Snoqualmie Tunnel, and Ginkgo Petrified Forest State Park.

Corfu Landslide. The Corfu Landslide, near the townsite of Corfu at the base of the north slope of the Saddle Mountains, covers more than 10 km^2 (4 square miles), and is one of the largest landslides in the state. Contributing factors to the slide are the presence of two faults that run through the slide body, and the undercutting of the toe of the slope by the waters of the late-Pleistocene Lake Missoula floods. Based on topography, it is likely that the slide mass is not presently moving, but has moved episodically in the past. The soil within the slide mass is highly disturbed and has a strength much lower than the surrounding rock. The Corfu Landslide was avoided by routing the centerline of the pipeline north of the toe of the landslide.

Snoqualmie Tunnel. The Snoqualmie Tunnel was constructed between 1913 and 1915 by the CMSP&P Railroad and was in continuous service as a railroad tunnel into the 1970s. It was out of use until recently when it was opened to pedestrian, equestrian, and non-motorized vehicle use.

The tunnel is approximately 3,627 m (11,900 feet) long and is mostly straight except for curves at the portals. The tunnel profile is a modified horseshoe shape with near-vertical sidewalls and a radius arch. It is entirely lined with reinforced concrete including concrete portal structures and headwalls at both portals. The tunnel has not been continuously maintained since the 1970s; however, the invert was graded and portions of the wooden drainage channel covers were replaced before it was reopened for recreational use.

Dames & Moore personnel performed a site reconnaissance of the tunnel on July 30, 1997. They observed zones of concrete deterioration, seepage from construction joints, and cracks in the lining. Groundwater flows ranged from drips to flows through the lining ranging from 3.8 to 7.6 liters (1 to 2 gallons) per minute. The concrete lining varied in condition from intact to spalled and decomposed as much as 0.3 m (1 foot) behind the original finished face of the concrete. Reinforcing steel was exposed in some of the deeper spalled areas. The pipeline would be buried in the floor throughout the length of the tunnel.

Ginkgo Petrified Forest State Park. The pipeline corridor would pass through Ginkgo Petrified Forest State Park from its western boundary toward Vantage leaving the park at its southern boundary south of Wanapum Campground. This park is listed on the National Natural Landmark Registry and has been listed by the National Park Service as a National Natural Endangered Resource. It includes an interpretive center and museum, interpretive and hiking trails, campgrounds, and facilities for swimming and boating. It is a showcase for approximately 200 species of fossilized wood and leaf material that are exposed in the bedrock and found lying on the ground surface in this area. The fossilized plant material, which originated in an environment of swamps and lakes in Miocene time (approximately 15 million years ago), is found within the upper part of the Vantage Sandstone and at the base of the overlying basalt flow. The plant fossils, which occur both within the sandstone and basalt beds and weathered out on the ground surface, are exceptionally well preserved in this locale because they were rapidly buried by lava and petrified.

3.2.1.5 Faults, Seismicity, and Liquefaction

Faults. Although the Pacific Northwest is tectonically and seismically active, relatively few young surface faults have been identified in the region, partially because seismic events large enough to propagate fault ruptures to the surface are infrequent. In the Puget Sound area, this also may be partially a function of the ability of the relatively thick unconsolidated sediments to take up the strain of deep-seated fault movement without a noticeable surface manifestation.

Section 2.15 and the Appendix A map atlas of the ASC show known and suspected faults of all ages along the pipeline corridor, as well as active and Quaternary faults within about 48 km (30 miles) of the pipeline corridor. Of these features, only active faults (those showing evidence of movement during the last 10,000 years) are considered to have a reasonable potential to rupture the ground surface during the life of the project. Faults with evidence of Quaternary movement (during the last 1.6 million years) are generally of less concern, but have the potential to generate strong ground motions of potential engineering significance within the pipeline corridor, particularly where they are spatially associated with historic seismicity. Faults that show no evidence of movement in Quaternary time are generally not considered to pose a risk of seismic potential over the life of engineered projects.

The pipeline corridor would cross several pre-Quaternary faults, mostly in the Cascade Mountains and in the vicinity of Ellensburg. However, it would not cross the mapped surface trace of any known active faults or faults with known Quaternary movement. The Seattle and Whidbey Island faults are potentially the most important active faults west of the Cascades. These faults have not generated earthquakes greater than magnitude (M) 6 historically, although the Seattle fault last ruptured the ground surface approximately 1,100 years ago during an earthquake estimated to be M 7-7.25 (Bucknam et al. 1992, Johnson and Potter 1994). The mapped trace of the Seattle fault extends from Bainbridge Island to the vicinity of Issaquah, approximately 12 km (7.5 miles) west of the pipeline corridor near Snoqualmie.

East of the Cascades, the closest Quaternary fault to the pipeline corridor is the Saddle Mountains fault. This fault has documented displacement of late Quaternary-age deposits, and probably had surface rupture associated with a large earthquake within Holocene deposits on the Smyrna Bench west of the Corfu Landslide (West et al. 1996). As mapped, the easternmost extent of this fault terminates approximately 2.4 km (1.5 miles) from the nearest segment of the pipeline corridor. However, the pipeline corridor may cross the buried eastern extension of the Saddle Mountains fault, which is inferred to be present beneath the Corfu Landslide deposits and the Quaternary loess and alluvial deposits east of the landslide. This fault is located in one of the most seismically active areas in the eastern half of the state (Geomatrix Consultants 1990, 1993).

The potential for surface rupture on other Quaternary faults within the region does not pose a recognizable hazard to the pipeline. However, several of these shallow crustal faults have the potential to generate strong ground motions of engineering significance within the pipeline corridor. Several of these Quaternary faults are spatially associated with earthquake epicenters of historical, instrumentally recorded events, but there has been no documented historical surface fault rupture on any of these faults. Similarly, there have been no historical, instrumentally recorded earthquakes of greater than M 5.0 associated with these faults, with the possible exception of the 1936 M 6.1 Milton-Freewater earthquake. This earthquake may have been associated with the Wallula fault zone, which exhibits displacements of Holocene deposits (less than about 10,000 years old) (Mann and Meyer 1993). This fault zone is located approximately 14 km (8.7 miles) south of the pipeline terminus at Pasco.

Seismicity. The locations of historical earthquakes in Washington and northern Oregon of potential engineering significance to the proposal are presented on Figure 3.2-1. Based on historical earthquakes and geologic studies of prehistoric earthquakes, an assessment of the likely severity of future earthquakes that could affect the pipeline corridor can be made.

Earthquakes are the result of sudden releases of built-up stress within or between the tectonic plates that make up the earth's surface. The stresses accumulate because of friction between the plates as they attempt to move past one another. For this proposal, three general sources of seismic activity are of potential engineering significance: (1) interplate earthquakes along the Cascadia Subduction Zone; (2) earthquakes originating within the Juan de Fuca plate; and (3) earthquakes originating in the shallow crust.

Cascadia Subduction Zone. The Cascadia Subduction Zone (CSZ) is the origin of the largest and most infrequent earthquakes in the region. The CSZ lies about 100 to 175 km (62 to 109 miles) west of the Washington coastline and marks the boundary between converging tectonic plates. Major earthquakes are believed to occur along this zone every several hundred years.

The CSZ has had little instrumentally recorded seismic activity in western Washington. A review of the existing literature suggests that an M 8.5 earthquake is a reasonable estimate of the largest event that could occur on this zone, and can be considered to be the maximum credible earthquake for this region (Atwater et al. 1995). This type of event would generate ground motions for a relatively long duration in the western portion of the pipeline corridor. Geologic evidence indicates that such an event last occurred approximately 300 years ago.

Juan de Fuca Plate. The second seismic source originates beneath the continental plate within the subducted Juan de Fuca plate. This source has generated two of the largest historical seismic events in the Pacific Northwest: the 1949 Olympia earthquake (M 7.1) and the 1965 Seattle earthquake (M 6.5). Intraplate seismic events are geographically more widespread and result from various structural sources in the crust. These types of earthquakes have historically caused the greatest amount of damage in the Puget Sound region. Based primarily on the historical seismicity of intraplate origin in western Washington, such as the 1949 M 7.1 Olympia event, and other subduction zones of the world, the intraplate zone is considered capable of generating earthquakes as large as M 7.5.

Shallow Crust. The third type of earthquakes originates in the shallow crust. Only one of this type of earthquake of magnitude greater than M 6 has occurred historically in the region of the proposal: the 1872 earthquake in north-central Washington. However, there is geologic evidence that a shallow earthquake of M 7.0 to M 7.25 occurred on the Seattle fault approximately 1,100 years ago (Bucknam et al. 1992, Johnson and Potter 1994), and the 1996 M 5.3 earthquake occurred at a depth of approximately 7 km (4.3 miles).

One of the most seismically active regions of the state with respect to shallow earthquakes is the Yakima Fold Belt (Geomatrix Consultants 1993). The largest instrumented earthquakes of the Columbia area were M 5.0 events in 1918 at Corfu, and at the Royal Slope of the Frenchman Hills in 1973 (Geomatrix Consultants 1990, 1996).

Potential Seismic Activity along Entire Pipeline Corridor. Based on the historic seismicity and tectonic considerations, the estimated peak ground acceleration levels derived by Frankel et al. (1996) are shown for the entire proposal area in the ASC. These levels are based on the peak ground accelerations that are considered to have a 10 percent chance of being exceeded in a 50-year period, which correlates roughly to a 500-year return period.

The estimated ground motion decreases from a maximum value of 0.29g at the western end of the pipeline (Thrasher Pump Station) to a minimum of 0.08g near the eastern terminus in Pasco. These levels of ground shaking could trigger landsliding; damage inadequately designed above-ground structures; or cause liquefaction of soils.

Liquefaction. Liquefaction is a phenomenon in which loose to medium dense, saturated, granular soils lose their shear strength during dynamic loading (usually during an earthquake) and behave as a fluid. Liquefaction causes soil settlement, and can result in lateral spreading or slope failure of a soil mass. Loose sandy soils saturated by shallow groundwater are the most susceptible to liquefaction. Clayey or cemented soils, which derive most of their strength from interparticle forces, are less susceptible to liquefaction. Similarly, non-saturated soils, regardless of composition or cementation, are not susceptible to liquefaction.

A preliminary evaluation of liquefaction potential is presented in the ASC (OPL 1998). The areas where surficial geologic materials are not susceptible to liquefaction (clay and rock) and those areas where near-surface groundwater (e.g., groundwater greater than 12 m [40 feet] below ground surface) is not known to be present were considered not susceptible to liquefaction. The remaining areas, predominantly young alluvial deposits in low-lying drainages and river and stream channels, were identified as having the potential for liquefaction. These areas are shown in the map atlas of the ASC and are listed in Table 3.2-3.

Areas along the pipeline corridor that have potential for liquefaction are underlain by alluvial sediments and are located in the larger stream valleys. These areas have the potential for liquefaction due to the presence of relatively loose granular soil and shallow groundwater. Based on OPL studies to date, the areas that have the greatest potential for liquefaction include:

- Snoqualmie River Valley (MP 8 to 9);
- Cherry Creek Valley (MP 17);
- Tolt River Valley (MP 23/24);
- Griffin Creek Valley (MP 26);
- Snoqualmie River Valley between Snoqualmie and North Bend; and
- Tillman Creek Valley near Cle Elum.

3.2.1.6 Stream Scouring and Lateral Migration

The potential for stream erosion by bed scouring and lateral channel migration is an important consideration in designing watercourse crossings for petroleum pipelines because these processes can expose a buried pipe to the hydraulic and abrasive forces of water flow, as well as sediment and debris movement. Both scouring and lateral migration occur primarily during flooding when streamflow forces are sufficient to erode bank and bed material.

Scour is the lowering of a streambed, which can occur naturally, typically in response to passage of a flood. It is most often caused by a change in stream hydraulics in response to a restriction or impingement of flow, or a deflection of floodflows. Changes can be induced by human manipulation of a stream, formation of log jams or ice jams, mass wasting of streambanks, or rapid influx of sediment and debris into the stream from mudflows or erosion associated with large storm events. Scour can also occur as relatively steady, progressive erosion as a stream gradually erodes toward its headwaters.

Table 3.2-3. Liquefaction Susceptibility

Liquefaction Zone	Map Atlas Page No.	Location	Length of Affected Pipe (m)	Ground or Aerial Reconnaissance	Field Investigation Performed	Liquefaction* Susceptibility	Lateral Spread/ Settlement Potential
1	5	Snoqualmie River Valley	1,676	Yes	Yes	4	Yes
2	8	No. Fk. Cherry Creek	305	Yes	No	2	No
3	11	Tolt River	488	Yes	No	NA	No
4	12	Griffin Creek	122	Yes	No	NA	No
5	14-16	Snoqualmie Valley	9,327	Yes	Yes	3	No
6	31	Cabin Creek	732	Yes	No	1	No
7	37	Tillman Creek	183	Yes	No	2	No
8	43	Swauk Creek	183	Yes	No Access	1	No
9	44	W. Fk. Dry Creek	274	Yes	No	1	No
10	45	E. Fk. Dry Creek	91	Yes	No	1	No
11	46-47	Reecer/Jones Creek alluvial fans	3,810	Yes	No	1	No
12	47	Currier Creek tributary	152	Yes	No	1	No
13	47-48	Currier Creek tributary	975	Yes	No	1	No
14	48	Currier Creek	152	Yes	No	1	No
15	53	Parke Creek	457	Yes	Yes	1	No
16 17	55	Parke Creek/Johnson Canyon	Primary 732 Alternate 2,774	Yes	Yes	1	No
18	78	Lower Crab Creek tributary	457	Yes	No Access	1	No
19	78	Lower Crab Creek tributary	305	Yes	No Access	1	No
20	79	Lower Crab Creek tributary	610	Yes	Yes	1	No
21	79	So. of Othello Pump Station	457	Yes	No	1	Yes
22	83-84	So. of Othello Pump Station	2,682	Yes	Yes	1	No
23	84-85	W. of Othello Channel	2,560	Yes	Yes	1	No

Liquefaction Zone	Map Atlas Page No.	Location	Length of Affected Pipe (m)	Ground or Aerial Reconnaissance	Field Investigation Performed	Liquefaction* Susceptibility	Lateral Spread/ Settlement Potential
24	86	Othello Channel	No intersect	Yes	No Access	1	No
25	88-89	Othello Channel	2,438	Yes	Yes	1	No
26	89-90	Othello Channel	1,554	Yes	Yes	1	No
27	91-92	Othello Channel to Esquatzel Coulee	4,572	Yes	Yes	1	No
28	93-96	Othello Channel to Esquatzel Coulee	10,668	Yes	Yes	1	No
29	96-100	Esquatzel Coulee to Pasco	12,192	Yes	Yes	1	No

*Key: 1. Predominantly non-liquefiable with potential for isolated pockets of loose granular soil
2. Typically non-liquefiable with potential for lenses of liquefiable sand and non-plastic silt
3. Predominantly liquefiable with potential for lenses of non-liquefiable clay
4. Liquefiable throughout the deposit
NA - No information available

Source: Based on OPL=s Application for Site Certification and additional information provided by Dames & Moore.

Lateral migration of stream channels is also a natural ongoing process, particularly on the outside of bends in alluvial rivers where a stream=s erosive power is typically greatest. However, either natural or human-made changes in stream geometry, blockage of flow, or increases in flow intensity can accelerate it. As with scouring, rapid changes in stream channel location can result from mass wasting of streambanks, formation of log jams, and mudflows.

Many of the larger streams that occupy channels within broad floodplains have the potential for substantial lateral bank erosion and channel relocation, as well as the potential for localized scouring of their beds. In the pipeline corridor, these types of streams include the Tolt River, Snoqualmie River, Little Creek, Cabin Creek, Big Creek, Yakima River, Swauk Creek, and Coleman Creek.

In the case of Cabin Creek, the floodplain has been artificially confined to less than 10 percent of its natural width by two bridge spans directly upstream of the pipeline crossing. This confinement, combined with periodic rapid discharges resulting from upstream landslide blockage and subsequent blowouts, has resulted in localized channel scouring and undermining of bridge abatements. This scouring could expose the pipeline if it is not placed below the maximum scour depth.

The smaller, steep-gradient streams in the mountainous areas tend to occupy deep ravines that confine their lateral migration. Where these stream channels are incised in competent bedrock, there is little potential for rapid erosion. However, where they occupy channels underlain by alluvial fill, many of these smaller streams could have significant scour potential. This is especially true in the Cascades, where many of the mountain streams are subjected to mudflows, torrential melt-water floods, and storm runoff capable of transporting large volumes of coarse sediment and debris.

3.2.2 Environmental Consequences

3.2.2.1 Proposed Petroleum Product Pipeline

Construction Impacts - Overall Proposal. Construction of the pipeline could have impacts on the environment by triggering mass wasting and soil erosion, disrupting streams as a result of directional drilling or trenching, disrupting fossils at Ginkgo State Park, or resulting in hazards to workers during construction in the Snoqualmie Tunnel. Potential construction impacts and measures that would be implemented to reduce them are discussed below.

Mass Wasting. Mass wasting could occur during construction as a result of one or more of the following: (1) undermining the toe of a steep slope or existing landslide area could trigger mass wasting which could then release fine-grained soil into adjacent water bodies; (2) soils placed near the top of an existing landslide or unstable slope could cause slope movements which could release fine-grained soils into nearby water bodies; and (3) soils stockpiled on steep slopes could fail or erode, running into water bodies nearby. Such events would have a temporary but minor to moderate impact on water bodies, depending on the volume of soil that was released, and the time of the year that it occurred.

The potential for undermining of a slope could be reduced by performing detailed reconnaissance just prior to construction in steeply sloping areas where the trench excavation would be parallel to topographic contours and at the toe of the slope, by maintaining geotechnically trained personnel onsite during construction in those areas, and by backfilling all steeply sloping portions of the trench on the same day as the excavation of the trench.

Overloading the top of a slope could be avoided by carefully planning stockpile and refuse areas. Such areas would be evaluated by a geotechnical expert to preclude the use of marginally stable or unstable slopes.

To prevent soil stockpiles from failing or being eroded, BMPs for erosion control would be applied (see Appendix C), and the stockpiles monitored for compliance, particularly in areas that have soils that are highly erodible when disturbed.

Implementation of the above measures during construction would greatly reduce the potential for mass wasting during construction, and would reduce the volume of any mass wasting that would occur. The resultant impact would be expected to be negligible to minor if adverse conditions are properly identified and mitigated.

Erosion. During construction, erosion could result from disturbance of soil by trench excavation, road building, and borrow operations. Fine soil particles entering a water body may affect plants and animals. The impacts from such erosion would range from negligible to moderate depending on the volume of sediment released and the time of year when it occurred.

Measures to control erosion during construction would concentrate on those areas adjacent to water bodies and/or steep slopes, and would include BMPs for scheduling (time of year), sequencing of construction activities, minimization of areas to be disturbed, diversion of surface runoff, sediment trapping, minimization of soil exposure, reduction of surface water velocity, timely revegetation, and frequent inspection of the work by qualified specialists. Properly implemented, these measures should result in only negligible impacts from erosion during construction.

Hazards in Snoqualmie Tunnel. In the Snoqualmie Tunnel, concrete and rock falls could occur in sections of the tunnel that are deteriorated, endangering the lives of workers, particularly when they are creating vibrations in proximity to these sensitive areas. The severity of such an event is not in its impact to the environment, but in the safety hazard it could pose to workers. If vibrations from rock excavation and blasting were to loosen deteriorating concrete, the construction could also increase the potential for future spalling, thus posing a somewhat greater hazard to future users.

The potential for concrete or rock fall in the Snoqualmie Tunnel could be reduced by placing an underlay lining of reinforced concrete or shotcrete in the more deteriorated or cracked sections of the tunnel. Where appropriate, rock dowels could be installed to support specific blocks of cracked concrete located in the crown or sidewalls. The need for such remedial measures would be carefully evaluated prior to initiation of construction. Proper design and implementation of remedial work in the tunnel would result in much safer working conditions in the tunnel.

Disruption of Ginkgo Petrified Forest State Park Fossils. Localized disruption of a nationally significant assemblage of fossilized forest remains could result from construction of the pipeline corridor through Ginkgo Petrified Forest State Park. Fossil beds are exposed at or near the ground surface, whereas other areas have petrified wood lying on the ground. The fossil beds and pieces of petrified wood on the ground surface would be disturbed by the trench excavation, road construction, and heavy equipment operation. Staging areas and stockpiling of equipment, excavated soils, and fill materials would damage any loose fossils and could also disrupt the fossil beds if they were placed directly on the fossil-bearing rock strata. Although the fossil beds are locally extensive and the footprint of the pipeline construction would be relatively small, this natural resource could not be restored once it was disturbed.

Stream Crossings, Sediments, and Drilling Fluids. Potential environmental impacts associated with construction at stream crossings would vary with the crossing technique that is employed at a given stream. Trenching within streambeds could significantly increase short-term sediment loading by disrupting the streambed sediments in the trench, by streambank and streambed disruption during construction, and by erosion resulting from improper selection and placement of trench backfill.

Existing bridges would be used to cross streams wherever practical. Elsewhere, BMPs would be followed to minimize the impact of stream trenching operations. These would include BMPs for scheduling (time of year), sequencing of construction activities, minimization of areas to be disturbed, diversion of streamflow, sediment trapping, minimization of bank disruption, timely revegetation, and frequent inspection of the work by qualified specialists. Properly implemented, the application of BMPs would result in negligible to minor impacts to stream channels.

Where minor impacts to water quality and habitat are not acceptable or where excavation methods are impractical, either directional drilling or horizontal directional drilling crossing technologies would be employed. These methods would not directly disturb the streambed or banks, so they would have considerably less impact than trenching. Nevertheless, where stream crossings would involve directional drilling or horizontal directional drilling, potential impacts during construction would include: (1) release of drilling fluid to the stream through pervious sediments or as a result of hydrofracturing the geologic materials during drilling; (2) loss of drilling fluid due to leakage from mud pits, and (3) failure to provide proper cleanup and disposal of used drilling fluids.

While mitigation measures for these potential impacts would be required for any drilled stream crossing, the potential for impacts is particularly great for crossing the Columbia River by horizontal directional drilling downstream of Wanapum Dam. This crossing would involve a 760 m (2,493-foot) long boring under the river, at a depth of at least 15 m (49 feet) below the riverbed, and of sufficient diameter to accommodate the 30 cm (12-inch) pipeline. Based on limited explorations conducted to date, the soils at this crossing are highly permeable and not very stable, a combination of conditions that has the potential to make the construction of this bore very difficult.

Specifically, horizontal directional drilling in highly permeable, coarse-grained sand, gravel, cobbles, and boulders such as those underlying the Columbia River would be difficult because of the potential for loss of circulation and the instability of the bore. There is a potential for collapse of the hole, which could result in the loss of both the bore and the drilling tools. There is also potential for release of drilling fluids to the river, either as a result of leakage through the permeable stream deposits, or by hydrofracturing the formation in an attempt to free drilling tools from a collapsed boring. Such a release could have an adverse environmental impact on water quality, depending on the volume of the materials entering the river and the time of the year. It could also result in a longer construction schedule and greater disruption of the near-shore environment.

OPL has identified several measures that would be used to reduce the potential impacts resulting from release of drilling fluid to the river, while improving the potential for success of a drilled crossing at the Columbia River (see Appendix C for details). On shore, the drilling fluids would be contained in lined basins. Fluids would not be allowed to discharge from the basins or the surface of the drill site to any stream. Once the drilling is completed, the fluids would either be buried in an excavated pit away from the shoreline or would be removed from the site using vacuum trucks for disposal in an approved landfill or other approved disposal site. Proper implementation of these measures would result in only minor impacts to the stream from the onshore construction activities.

OPL has proposed measures to reduce the potential for leakage of drilling fluids from the horizontal bore into the river during drilling. Specifically, OPL proposes to conduct additional explorations using vertical boreholes to better characterize subsurface conditions along the horizontal bore path. The proposed drill path would provide considerable sedimentary cover over the boring, and high-viscosity drilling mud would be used to minimize infiltration into the sediments. OPL also plans to use only bentonite drilling fluids (no oil) for drilling, and to monitor the drilling fluid pressure and flow rate during drilling to anticipate blowout situations and to monitor fluid loss to the formation. These measures would reduce the potential for a major leak from the bore into the river. However, the available subsurface data indicate that there would still be a potential for leakage to the river through the pervious soils. More significantly, there is a potential for collapse of the borehole, which might trigger recovery measures that could increase the chances of hydrofracturing the formation or leaking drilling fluids to the river. OPL has also indicated that partial casing of the borehole and grouting and redrilling could be accomplished to improve borehole stability, if necessary.

Construction Impacts - Columbia River Approach Options. Impacts to the geologic environment and ground stability resulting from construction of either of the YTC corridor segment options approaching the Columbia River would be similar to those resulting from construction of the proposed route, with the exception that they would avoid passing through Ginkgo Petrified Forest State Park and through a 2.4 km (1.5-mile) wide landslide to the east of the park. Consequently, disruption of the fossil beds in the park would be eliminated, and the risks of ground instability in the landslide mass could be avoided.

Construction Impacts - Columbia River Crossing Options. In addition to the proposed Columbia River crossing method (horizontally drill a crossing downstream from Wanapum Dam), OPL has identified four alternative Columbia River crossing routes: dredging a crossing north of I-90, attaching the pipeline to the I-90 Bridge at Vantage, attaching the pipeline to the Burlington Northern Beverly Railroad Bridge south of Wanapum Dam, or placing the pipeline on Wanapum Dam. There are also various approach routes to the alternative crossing sites. The horizontal directional drill is OPL=s preferred crossing method at this time for the following reasons:

- Whereas the site soil conditions are not optimum for a horizontal directional drill south of Wanapum Dam, OPL has determined that current technology exists to successfully complete the installation with a low probability of fracturing out and releasing drilling fluids to the river.

- The other crossing options include using the I-90 Bridge, Beverly Railroad Bridge, or Wanapum Dam to support the pipeline, or dredging a pipeline trench across the Columbia River north of the I-90 Bridge. The options involving supporting the pipeline on an existing structure would all eliminate geologic impacts that could result from a drilled or dredged crossing. However, since the rights to use these structures have not been secured to date from the appropriate regulatory agencies, these alternatives are potentially unavailable as crossing options.

- OPL has entered discussions with the Washington State Department of Transportation (WSDOT) about the possibility of using the I-90 Bridge; to date WSDOT has not made a decision about the acceptability of using the bridge. This would be the least expensive of the alternatives and would likely have the fewest environmental impacts.

- Use of the Beverly Railroad Bridge would require obtaining permission from Washington State Parks and Burlington Northern Railroad, who is considering reactivating the bridge for railroad traffic. The potential for future railroad use, the greater length of exposed pipeline, and the unknown but questionable structural integrity of the bridge all reduce the desirability of this option. Without proper rehabilitation of the bridge and abutments, this route might also pose an operational risk of pipeline rupture above the river resulting from damage to the bridge by seismic shaking.

- OPL has also applied to Grant County Public Utility District for a permit to place the pipeline along the upper portion of Wanapum Dam. However, no decision has been made to date as to whether that permit would be approved.

- The other option, which would involve a trenched crossing north of the I-90 Bridge, is considered by OPL to be the least preferred alternative. A wet trench method would be used, which would result in release of sediment into the river and would disturb the shoreline. While this method is feasible, it would require mitigation measures to minimize impacts to fish habitat and shorelines.

The alternate routes for the dredged and I-90 Bridge crossings continue east on the north side of I-90, cross the river, and continue south along the east side of the Columbia River, rejoining the proposed pipeline corridor approximately 2.5 km (4 miles) east of Wanapum Dam. With the exception of the Columbia River and Ryegrass Coulee, streams crossed by these two alternative routes (crossings 24a to 24c) are intermittent and would be crossed when they are dry. Ryegrass Coulee would be a bored crossing.

There are also several alternative approach routes which originate at the YTC segment option north of I-90 and extend to the proposed crossing location (crossing 223) and the Burlington Northern Railroad Bridge crossing. Each of these options crosses similar terrain, where there would be only negligible geologic impacts during construction except where these alternative routes cross the Ginkgo Petrified Forest State Park in the slopes above the Columbia River. Impacts in the park are discussed above, whereas the other impacts in this area are discussed under AStream Crossings and Landslide Areas - Columbia River@ in the operational impacts section below.

Operational Impacts - Overall Proposal. Mass wasting and erosion, landslides, seismic disturbance and liquefaction, and stream scouring or migration could all result in breakage of the pipeline during operation. The resulting impacts would vary in magnitude and type, depending on the location of the break relative to sensitive environments and water resources. The potential risk of a spill from the pipeline is addressed in Section 3.18, Health and Safety. Potential impacts from such ground movements, and measures that either have been or would be implemented to prevent or minimize those impacts, are described below.

Mass Wasting and Erosion. Potential impacts from mass wasting and erosion include the following:

- Breakage of the pipe as a result of unavoidable subsurface landslide movements.
- Channeling of ground and/or surface water along trenches into a landslide mass or colluvium on steep slopes, resulting in initiation or reactivation of a landslide.
- Breakage of the pipeline by surface mass wasting movements, such as avalanches or mudflows.
- Loss of ground by erosion from beneath the pipe, resulting in breaking the pipeline.
- Failure of trench backfill, particularly on steep slopes.
- Failure of a culvert or bridge footings below the pipeline, resulting in washout of the overlying embankment and pipeline.
- Release of product into an aquifer or an adjacent water body as a result of pipe extension or compression caused by ground movement.

The environmental impacts resulting from such failures could range from minor to major depending on the location where a pipe break occurred with respect to sensitive environments, the timing of the release with respect to the life cycle and presence of sensitive species, and the volume of product that was released. Potential general measures OPL has proposed to minimize mass wasting are described in Appendix C.

Table 3.2-4 indicates the types of specific measures that have been or would be used to address mass wasting hazards at specific sites along the pipeline corridor. Additional site-specific geotechnical investigations would be required to design selected mitigation options. Data collection methods would include subsurface exploration and/or geophysical exploration, followed by detailed slope stability analyses and design of slope stabilization measures. Where possible, the pipeline corridor has already been adjusted to avoid mass wasting features. However, where this was not feasible, other measures would be employed during design and construction such as installation of strain gauges to detect pipe movement, thicker pipe walls, slack loops, and buoyancy compensation. For some locations, remotely operated block valves (shut-off valves) would be an appropriate safety

Table 3.2-4. Mass Wasting Hazard Assessment

Geologic and Hazard Map Page	Stream Crossing or Alternative Route	Hazard Potential		Mitigation Measures								
		Shallow Failure[a]	Deep Failure[b]	Avoidance	Strain gage on pipe	Long Term Monitoring	Drainage	Buttress	Increase Burial Depth	Additional Exploration for Design	Flexible Couplings	Block Valves[f]
4	E of 9	L	L									
5	W of 11	H	L				x		x	**x**		x
5	12&13	M	M				x	x		**x**		
6	14&15	H	L				x	x	x	**x**		
8	20&21	H/**H**	**H**/L			x	x	x	x	**x**		x
11	NW of 26	M*	M*							**x**		
11	SW of 27	H*	H*		x	x	x			x	**x**	x
12	N of 28	M	L						x	**x**		
12	S of 28	M	L						x	**x**		
14	37	H	M				x	x	x	**x**	x	
17	N of 44	M	L						x	**x**	x	
17	S of 44	M	M						x	**x**		
18	E of 44	M	L						x			
18	45&46[c]	H	L				x	x	x	**x**	**x**	x
18	46 to 49[c]	M	L						x	**x**	**x**	
19	50 to 56	L	L				x			**x**	**x**	
20	59 to 61[d]	L	L						Embank-ment only			
21	61 to 67[d]	M	L				x			**x**		
21	67 to 69[d]	M	L				x			**x**		
23	W of 78[d]	L	L									
23	E of 78[d]	M	M									
24	E of 83	**M***	**M***							**x**		
25	N of 85[d]	M*	L		**x**					**x**		
26	93 to 95[d]	L	L									
30-31	113 to 116	M*	M						x	**x**	x	
37-38	133 to 136	M	L				x	x	x	**x**	x	
41	W of 145	M	L				x	x	x	**x**	**x**	x
41	W of 147	H	M				x	x	x	**x**	**x**	x
42	147&148	L	L									
42	E of 148	M	L						x	**x**	**x**	
43	150 & 151	H	L*	x					**x**	**x**	**x**	
43	151 to 153	M*	M*		x					**x**		

Table 3.2-4. Mass Wasting Hazard Assessment

Geologic and Hazard Map Page	Stream Crossing or Alternative Route	Hazard Potential		Mitigation Measures								
		Shallow Failure[a]	Deep Failure[b]	Avoidance	Strain gage on pipe	Long Term Monitoring	Drainage	Buttress	Increase Burial Depth	Additional Exploration for Design	Flexible Couplings	Block Valves[f]
44	E of 156	L	L									
45	157	L	L									
61a/62a	Alt. Segment 14	L	M*	x					x	**x**	**x**	x
82	255[e]	L	L	x								
The following Mass Wasting locations were found on alternative pipeline routes and are not located within the proposed route.												
61	9a	L	L	x								
61	Alt 3	L	M*	x						**x**		
61	Alt 13	L	M*	x						**x**		
62/62a	Alt 13	L	M*		x	x		x		**x**	**x**	x
62a	16b-16g	L	L									
62b	N of 16a	L	L									
63a	SE of 24a	L	L									
78a/79	E of 246	alignment	rerouted	x								
80a	250-251	alignment	rerouted	x								
86 & 87	S of 261[e]	alignment	rerouted	x								

[a] less than 10 feet deep
[b] greater than 10 feet deep
[c] occurs on federal lands administered by the U.S. Bureau of Land Management
[d] occurs on federal lands administered by the U.S. Forest Service
[e] occurs on federal lands administered by the U.S. Bureau of Reclamation
[f] block valves that are not shaded correspond roughly to valves OPL is proposing as part of the project at crossings of large rivers/streams (see Table 2-3). They are eated here to emphasize their importance in minimizing hazards at mass wasting areas as well. The valves that are shaded fall between valves proposed by OPL and are sented here as additional suggested mitigation.

WRT = With Respect To: H = High, M = Moderate, L = Low

* Pending further site investigations

Shading indicates additional mitigation recommended by the EIS team; non-shaded items are part of OPL's proposal.

Source: Based on information provided by OPL and field reconnaissance by the EFSEC consultant team.

measure. Properly implemented, these measures would reduce but not eliminate the potential for impacts resulting from pipeline breakage caused by mass wasting. For example, a block valve damaged by a slide could no longer function as a spill volume reduction mechanism, nor would such a valve completely eliminate a release in the event of pipe breakage.

Stream Crossings and Landslide Areas

Peoples Creek. Potential failure of the slope at Peoples Creek (stream crossing 15) could occur if the pipeline were buried at a shallow depth and became compressed or extended by the sudden or gradual movement of colluvium on the steep hillside. It is very unlikely that backfill can be placed and suitably compacted on the 60-degree, weathered andesite slopes on the lower portion of this hillside, and failure of improperly placed backfill could result in the uncovering of the pipeline and undermining of support. Rupture of the pipe here could result in the spill of product directly into the creek, which could have a moderate to major environmental impact, depending on how much product reached the stream, the time of year when the spill occurred, and how quickly the spill could be remediated. Peoples Creek drains into the Snoqualmie River 2 km (1.2 miles) downstream of the crossing.

The potential for slope failures along this creek would be mitigated by burying the pipeline below the depth of loose colluvial soil, and by providing in-trench subdrainage on the slope above the rock/soil contact. To design such measures, subsurface explorations would need to be accomplished and detailed geotechnical studies performed.

Cherry Creek. Future movement of existing landslides on the southern slope of Cherry Creek (stream crossing 20) could compress the pipeline at the toe of the slope or extend it at the top of the slope. Such movement could rupture the pipeline, causing spill of product into the creek. The impact could range from moderate to major depending on the size of the spill, the time of year that it occurred, and the time required to remediate it.

OPL has proposed to mitigate the potential for landsliding at this sensitive site by deep burial of the pipeline, and providing long-term monitoring of groundwater levels and ground movements to anticipate and detect potential pipeline ruptures. They would also install block valves at the top of slopes on either side of the valley to reduce the magnitude of any petroleum release. These measures would reduce the potential for a release of product to the stream; they would not serve to stabilize the hillside or appreciably reduce the potential for breakage of the pipeline in the event of a landslide.

Tolt River Valley. Movement at the deep-seated active slide on the south side of the Tolt River Valley (stream crossings 26 and 27) would likely occur either at the top or toe of the slide mass. At the top of the slide the pipe would be pulled apart, whereas at the toe the pipe would be buckled by compression. If the pipe was pulled apart, the spilled product would have about 610 m (2,000 feet) of forested sloping ground to run over before it reached the Tolt River, and because the ground is very pervious, much of the product would infiltrate into the ground. If buckling at the toe ruptured the pipe, product would likely run directly into the Tolt River and result in a moderate to major impact to the stream, depending on the amount of product released and the time required to remediate it.

Design measures proposed by OPL for the Tolt River landslide would include drainage incorporated into the pipeline trench to capture as much subsurface water as possible and improve the stability of the landslide. The earth mass and the pipeline would be monitored with strain gauges on the pipeline and slope inclinometers and groundwater monitoring wells in the ground, all of which should be capable of being monitored remotely. Block valves should be installed on the slopes to the north and south of the creek to reduce the magnitude of a release should a pipe break occur. A subsurface exploration program would be conducted to better understand this slide and to provide information for geotechnical evaluations. These measures would reduce the potential for and impact of a break in the pipeline due to mass wasting. They would not, however, eliminate the potential for released product entering the stream. Such an event could have a minor to major environmental impact on the river depending on the volume of product released and the time when it occurred.

Columbia River. The proposed pipeline route would traverse the middle of a large slide mass above the west shore of the Columbia River (ASC atlas page 62a). Reactivation of the slide, with movement perpendicular to the pipeline, could bend the pipe and cause rupture, resulting in the spill of product into the Columbia River. Such a spill could have a moderate to major environmental impact on the river depending on the volume of product released, the timing of the release, and the response time required to remediate the spill. The mapped landslides just west of the Columbia River (ASC atlas pages 61, 61a, 62 and 62a) would be avoided if the YTC pipeline corridor crossing below Wanapum Dam was used. If the alternate routes are considered, all of them would also avoid the slides except for one segment south of I-90 that ties into the north-south proposed alignment parallel to the west shore of the Columbia River, which would cross through the large landslide shown in the upper center of atlas page 62a. This alternate route would cross the headscarp, perpendicular to the contours such that it would be subjected to extension if the slide reactivated. Extension could result in the spill of product onto the ground and overland flow to the river.

To mitigate the areas where the proposal and alternate routes would cross through the dormant slide mass, OPL proposes to conduct a detailed subsurface exploration program to design a buttress for the slide mass. They would also plan to install a long-term monitoring system, including strain gauges on the pipeline and inclinometers and groundwater level monitors in the ground. These measures would both reduce the potential for and impact of a product release resulting from landsliding.

Seismic Hazards and Liquefaction. Modern steel pipelines with arc-welded joints generally have low vulnerability to damage from ground shaking and gradual lateral/vertical displacement. However, there have been earthquake-induced pipeline failures associated with abrupt ground failures such as fault rupture, slope failures, or lateral spreading of liquefied soils.

Impacts resulting from seismic activity could include pipeline rupture and leakage or spillage into surface water bodies and aquifers. The severity of such an impact would depend on the size of the resulting spill and the response time required for remediation. In the case of a large seismic event, it is anticipated that response time could be lengthened because of competing needs and disruption of infrastructure. Such rupture resulting from a seismic event could occur in the following ways:

- Surface rupture along an active fault could break a pipeline that crosses the fault plane.
- Seismic ground shaking could trigger landslides in areas of marginal slope stability, as discussed above with respect to impacts resulting from mass wasting.

- A bridge or trestle crossing that was not adequately designed or maintained to withstand sufficient seismic shaking could collapse and rupture the pipeline, releasing product into the underlying stream or river.

- Liquefaction of the soils surrounding the pipeline could result in the pipeline becoming buoyant, allowing it to float up toward the ground surface while the soil is in a liquefied state. Similarly, liquefaction could result in differential settlement of the soils underlying the pipeline. Although modern steel pipelines are flexible and can tolerate some gradual movement, either condition could result in stress or breakage of the pipeline.
- Lateral spreading can cause large transverse displacements that could result in breakage of the pipeline. Pipe failure could occur by lateral bending at the edge of the liquefied zone where the pipe runs across the spreading direction, or by compressive buckling where the pipe runs down a slope underlain by liquefied soil.

The pipeline, pump stations, and loading facility would include conservative seismic design and performance criteria specific to the anticipated seismic risks in their locations. Foundation designs would include parameters to minimize impacts from ground shaking and ground rupture which could result in adverse impact to the pipeline and associated structures. These designs would be based on borings or other geotechnical studies accomplished to develop site-specific measures to be incorporated into the pipeline and facility design.

In addition, where feasible, the pipeline corridor has been selected to avoid mapped active or Quaternary faults which are particularly sensitive to seismic events. In areas where liquefaction or lateral spreading poses a hazard, site exploration and data analysis would be performed to select an appropriate construction technique to mitigate the potential for damage to the pipeline. Studies have been conducted to evaluate existing bridges that would be used to support the pipeline. Upgrades and repairs would be implemented where studies indicate the structures are not sufficiently stable to withstand the design earthquakes. Other potential design measures proposed by OPL for impacts resulting from seismic shaking and liquefaction are described in Appendix C.

With proper engineering design and adequate explorations to identify liquefiable soils, these measures should greatly reduce the potential for pipeline rupture due to liquefaction and the resultant impacts. Additional measures recommended to reduce the impact that might result from surface fault rupture along the Saddle Mountains Fault are described under "Additional Proposed Mitigation Measures".

Scouring and Lateral Migration. Changes in stream hydraulics as a result of constructing the pipeline crossings could have long-term effects on stream channel stability. One of these effects could be the increased potential for scouring or lateral migration, and the resultant exposure and damage of the buried pipeline within the stream.

Stream scouring could result in locally lowering the streambed and exposing the buried pipeline. Such an occurrence would likely happen during flooding, at a time when sediment or debris transport was at a peak and would have the greatest potential to damage the exposed pipeline. A pipeline breakage resulting from scour would result in spillage or leakage of fuel directly into the stream and rapid transport of the product to receiving waters.

Rapid lateral migration of a stream channel could also uncover the pipeline where it had been buried within the stream floodplain, exposing it to potential damage from sediment and debris transport. The pipe could also be damaged if lateral migration or scour removed the soil covering the pipe, allowing it to float out of its trench. Stress caused by such floatation could possibly break the pipe, resulting in discharge of product directly into the stream.

The watercourses the pipeline corridor would cross include large meandering streams that drain the west side of the Cascade Mountains and Puget Sound; steep-gradient, high-energy mountain streams where the corridor would cross the Cascades near Snoqualmie Pass; and relatively low-energy streams that drain the semi-arid plains of eastern Washington. Consequently, a wide range of hydrologic, geologic, biologic, climatic, and watershed-use factors would need to be considered in designing stream crossings for the pipeline. Specifically, these factors would have to be evaluated to assess the long-term impacts of stream erosion in order to determine how deep the pipeline would need to be placed in order to remain safely below the potential scour depth. This depth would have to be determined not only in the present-day channel, but also across the full width of any floodplain that could experience lateral migration of the channel.

Potential measures proposed by OPL to reduce the impacts from pipeline breakage resulting from stream scour and lateral migration include the following:

- Those streams determined to be scour critical, based on a screening-level study of scour potential conducted by OPL, would require a detailed analysis of geomorphology, hydrology, hydraulics, and sediment transport to determine the depth that the pipeline would be buried.

- Pipe burial depths below scour level would be used for the full width of the stream floodplains where lateral migration could occur, not just the streambed.

- BMPs for minimizing the construction footprint and controlling erosion within and adjacent to stream crossings would be applied to minimize disruption of the streambed and adjoining areas (see Appendix C for BMPs).

- The pipeline would be encased in concrete at stream crossings to reduce the effects of buoyancy in the event that overlying soils were eroded. Such a coating would also protect the pipeline from impact in the event that it was exposed by stream erosion and provide an improved ability to withstand undermining of the pipeline.

The level of investigation proposed by OPL to evaluate scour and lateral migration potential at most stream crossings would not be adequate to determine sufficiently conservative burial depths for the pipeline along much of the proposed route. Consequently, these measures alone would not sufficiently reduce the potential for stream erosion to expose the pipeline, which could, in turn, result in releases of product directly into streams during storm runoff events. Therefore, additional mitigation measures are recommended later in this section.

Operational Impacts - Columbia River Approach Options. Geological operational impacts for the YTC segment and other options would not differ from those for the proposed pipeline corridor with the exception that the risk of a release caused by landsliding would be reduced for all options except the one that would pass through the large landslide mass shown on ASC map atlas page 62a.

Operational Impacts - Columbia River Crossing Options. Use of the Burlington Northern Beverly Railroad Bridge in its current condition could pose an unacceptable risk of pipeline breakage during the life of the project. If this option were selected, structural rehabilitation of the bridge abutments may be required, pending a more detailed review of the structural integrity of the bridge and its abutments.

Cumulative Impacts. Increased risk of negative cumulative effects to watersheds could result from erosion in watersheds with harvested and roaded areas upstream; multiple pipeline crossings (see the discussion in Section 3.6); disturbances by wildlife; heavy winter applications of sand and gravel to highways and roads; other near-stream ground disturbing activities; and others. Turbidity of the water column would result in temporary impacts, even on a cumulative basis. Cumulative effects could be more pronounced in basins that would contain numerous invasive crossings of streams (e.g., South Fork Snoqualmie River), where sediment from several tributaries would be transported to a mainstem system. High fine sediment concentrations in the streambed often have negative implications for aquatic ecology. However, after construction, and after revegetation and other stabilization measures are in place, no cumulative impacts are anticipated. Cumulative effects on water quality are discussed in more detail in Section 3.6.

3.2.2.2 No Action

Without the proposal, there would be no impacts to geology or soils. Geotechnical issues would have no impact on increased trucking and barge activity.

3.2.3 Additional Proposed Mitigation Measures

3.2.3.1 Construction Mitigation and Subsequent Impacts

Columbia River Crossing. To improve the chances of successful construction of the horizontal boring under the Columbia River, while reducing the potential for releases of drilling fluid from the bore to the stream, several additional mitigation measures are proposed. They would involve detailed data gathering prior to construction and carefully applied practices during the actual boring, as described below:

- Involve qualified contractors in the planning and implementation of this crossing. Contractors could be retained to provide a preliminary project feasibility study and initial drill alignment. Such a feasibility study may indicate additional problems that would not otherwise be identified until during the drilling operation. Once the project is underway, an experienced and pre-qualified driller should always be on the drill rig. This may require pre-qualification of drilling contractors, as well as having certain personnel on the job at all times.

- Perform additional explorations to better determine ground conditions before developing the final design for the pipeline crossing. Of greatest use would be a test horizontal directional drilling program to determine the feasibility of constructing a full-scale crossing. This may be the only way to substantially improve upon the current understanding of site conditions. Such a pilot test bore would provide insight on how to accomplish the crossing with the least potential for a release of drilling fluids. It would also provide data for potential contractors to prepare a reasonable bid to do the work.

  Regardless of the explorations that are conducted in advance, horizontal directional drilling in highly permeable, coarse-grained sand, gravel, cobbles, and boulders such as those underlying the Columbia River could be problematic because of the potential for loss of fluid circulation and the instability of the bore. There is a significant potential for collapse of the hole, which could result in the loss of both the bore and the drilling tools. Similarly, stopping during the final pull in such soils could result in lockup of the pulling string and cause loss of the bore. There is also a potential for a release of drilling fluids to the river, either as a result of leakage through the permeable stream deposits, or by hydrofracturing the formation in an attempt to free drilling tools from a collapsed boring. Such a release could have a water quality impact on the river. It could also result in a much longer construction schedule than is planned and greater disruption of the near-shore environment than would otherwise occur.

- If the soil conditions are as currently anticipated, measures to improve the bore stability would greatly improve the potential for a successful horizontal bore under the Columbia River. One such measure would be to pre-assemble the entire pipe to allow the contractor to install the pipeline in one continuous pull. This would eliminate the need for stopping the pull to weld on additional pipe. Complete grouting of the hole during drilling should also be considered to help stabilize the formation. Based on the current understanding of the soil conditions, these additional mitigation measures could be critical to the successful completion of this bore, and would reduce the potential for circumstances which could result in leakage of drilling fluids into the river.

- Consideration should also be given to use of a polymer drilling fluid that would break down and have less impact on the aquatic environment than would bentonite in the event that it was released to the river.

Ginkgo Petrified Forest State Park

- A geologic survey of surficial and near-surface deposits should be considered within Ginkgo Petrified Forest State Park to identify a route that would minimize destruction of the fossil beds. Use of an existing maintenance road should be considered for the pipeline trench, and a minimal width for the pipeline corridor should be considered where construction could otherwise disturb the fossil beds.

3.2.3.2 Operational Mitigation and Subsequent Impacts

Landslides. Table 3.2-4 provides an overview of additional measures suggested to reduce mass wasting impacts (see shaded items). Specific measures include:

- Geotechnical investigations should be performed at the mass wasting areas having either high or moderate potential for slope failure. These investigations would help to define the slide potential and to identify practical and effective measures to reduce the potential for slope failure.

- On the rock portion of the slope at the Peoples Creek crossing, and in similar environments, the backfill in the trench should be concrete to buttress the slope and protect the pipe. To design such measures, subsurface explorations should be accomplished and detailed geotechnical studies performed.

- Block valves south of the slide and on the slope north of Cherry Creek should be required to stop flowing product in the event that pipeline or ground movement is detected. Because most of the earth movement at this site is caused by surface and subsurface water, drainage mitigation measures would likely be the most effective means for increasing the stability of the slope. While increased depth of pipe burial could be effective, a subsurface exploration program would be necessary to determine if other measures such as buttressing would be required to stabilize the hillside and the pipe.

- Flexible couplings should be considered at the top and toe of the landslide along the south slope of the Tolt River Valley to allow for creep movements of the earth mass. Pipeline block valves should be considered at this location. Additionally, block valves should be installed south of the top of the slide area and on the slope north of the Tolt River in the event pipeline or ground movement is detected.

- For the proposed routes and the alternatives that traverse a large landslide west of the Columbia River crossing, additional measures should be considered to further reduce the impact of a landslide-related pipeline break and product release into the Columbia River. Pipeline block valves installed at the west side of the slide would allow for a shut-off of product flow in the event that pipeline or ground movement were detected or breakage were to occur. This measure, along with measures proposed by OPL, would both reduce the potential for and magnitude of a product release into the Columbia River.

Fault Rupture. Along the Saddle Mountains, the corridor would cross an area where the buried extension of the active Saddle Mountains fault may exist. The potential for surface rupture along this fault requires further evaluation during design. If the fault extends under the pipeline alignment, mitigation could include:

- installation of flexible couplings across the fault zone,

- # use of reinforced pipe with increased wall thickness to reduce the potential for breakage, and/or
- # installation of block valves to minimize a potential release in the event of a rupture.

Stream Scour and Lateral Migration. Several additional mitigation measures are described below that would reduce the potential for breakage of the pipeline by stream scour and lateral migration. These measures should significantly reduce the potential for impacts resulting from breakage of the pipeline as a result of stream scour. Because of limitations in the current understanding of stream and hillslope processes, it is not feasible to completely eliminate the potential for such impacts.

- # Detailed evaluations of scour potential at individual stream crossings would be required to determine appropriate depths of pipeline burial to minimize the potential for exposure of the pipeline. The depth of burial would need to exceed this estimated scour depth by a conservative factor to account for uncertainties in the scour evaluation. The generalized screening level approach accomplished to date by OPL would be useful in evaluating the scour potential of low gradient (1 to 2 percent) streams with respect to fluvial sediment transport processes. However, the scour potential of steeper gradient streams, including all of those within the Cascades, needs to be reevaluated to consider the high shear stresses applied to the beds of these streams. The scour evaluations also need to consider the effects of rapid gully advancement in steep disturbed streams, flow constrictions, log jams, debris flows, and headward migration resulting from stream degradation, all of which have been observed at or near proposed stream crossings.

- # In areas where scour studies indicate that the potential scour depth would exceed reasonable trenching depths, the stream crossings could be accomplished by horizontal directional drilling.

- # Block valves could be used on streams where there is a high or unpredictable scour potential to reduce the impact of a pipeline break that occurred as a result of a rapid scouring event.

- # For areas where the pipeline would be placed in an embankment above or below existing culverts, studies would be necessary to confirm that the culverts are adequately sized to accommodate peak flood events. Within the Wenatchee National Forest, larger culverts would be required to prevent flood events from eroding the embankment and risking breakage of the pipeline. (The ASC indicates that undersized culverts that are identified will be replaced as a pipeline construction mitigation measure.) Where these areas are susceptible to mudflows and debris flows, consideration should be given to horizontal directional drilling and installation of block valves.

- # If horizontal directional drilling is selected for the Columbia River crossing, a flood study should be done to assess if floodwaters would cover the launch and receiving pit areas during design peak flows. If so, provisions would be necessary to protect the pipeline from damage that could be caused by scour where it enters and leaves the bored crossing.

Such measures could include use of energy dissipaters, riprap, or other bank protective measures designed for the specific application.

Seismic Stability. If the Beverly Railroad Bridge alternative is to be used for the Columbia River crossing, a detailed structural analysis and seismic stability analysis will be necessary to determine whether substantial rehabilitation of the bridge is necessary.

The trench excavated for pipeline installation should be specially designed to maximize pipeline flexibility in case of seismic events. Such construction should consist of 1:1 sloped trench sidewalls and placement of free-draining backfill in the trench.

LIST OF ACRONYMS

LIST OF CITATIONS